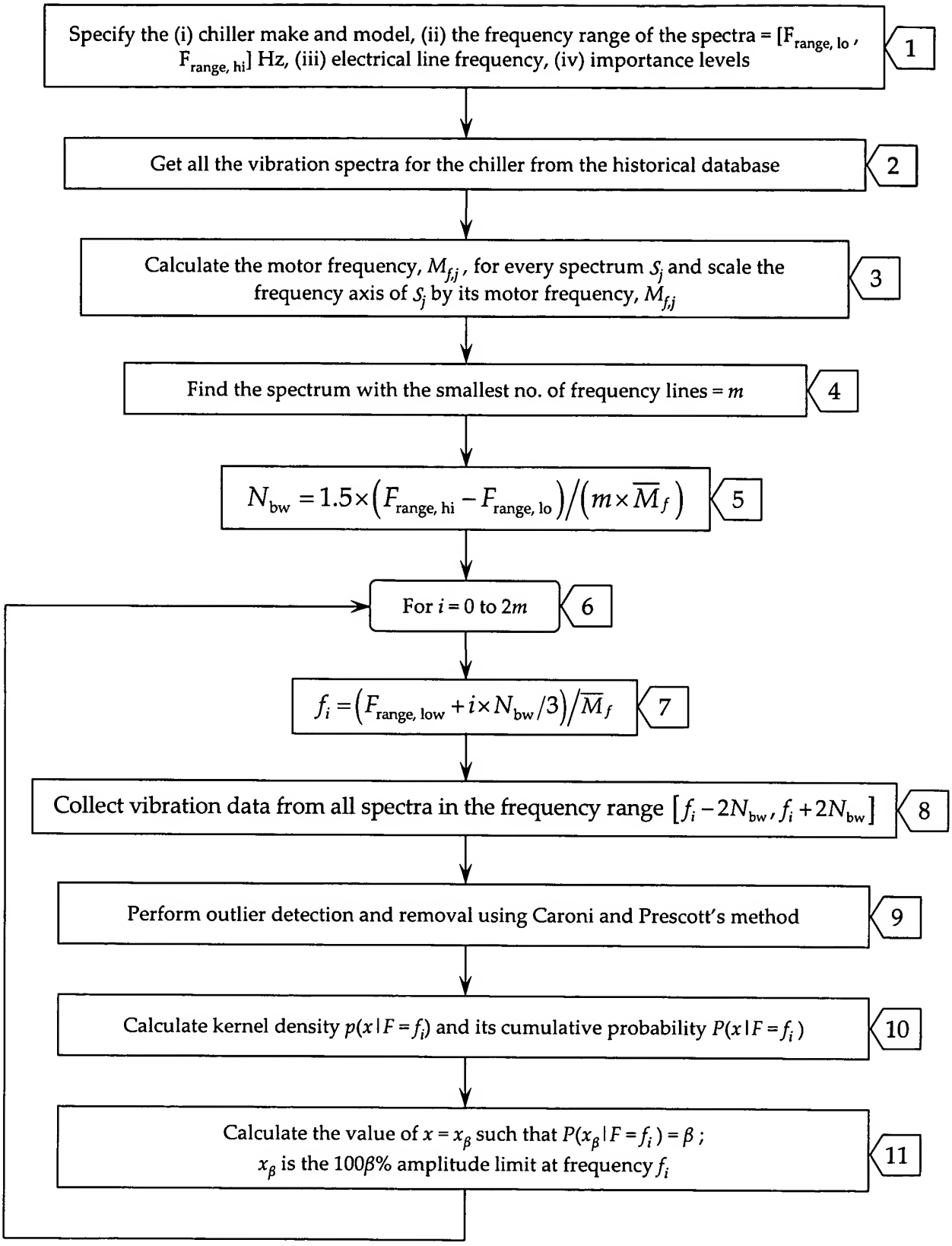

Specify the (i) chiller make and model, (ii) the frequency range of the spectra = [$F_{range, lo}$, $F_{range, hi}$] Hz, (iii) electrical line frequency, (iv) importance levels
1
Get all the vibration spectra for the chiller from the historical database
2
Calculate the motor frequency, $M_{f,j}$, for every spectrum S_j and scale the frequency axis of S_j by its motor frequency, $M_{f,j}$
3
Find the spectrum with the smallest no. of frequency lines = m
4
$N_{bw} = 1.5 \times \left(F_{range, hi} - F_{range, lo}\right) / \left(m \times \overline{M}_f\right)$
5
For $i = 0$ to $2m$
6
$f_i = \left(F_{range, low} + i \times N_{bw}/3\right) / \overline{M}_f$
7
Collect vibration data from all spectra in the frequency range $[f_i - 2N_{bw}, f_i + 2N_{bw}]$
8
Perform outlier detection and removal using Caroni and Prescott's method
9
Calculate kernel density $p(x \mid F = f_i)$ and its cumulative probability $P(x \mid F = f_i)$
10
Calculate the value of $x = x_\beta$ such that $P(x_\beta \mid F = f_i) = \beta$;
x_β is the 100β% amplitude limit at frequency f_i
11

Figure 1

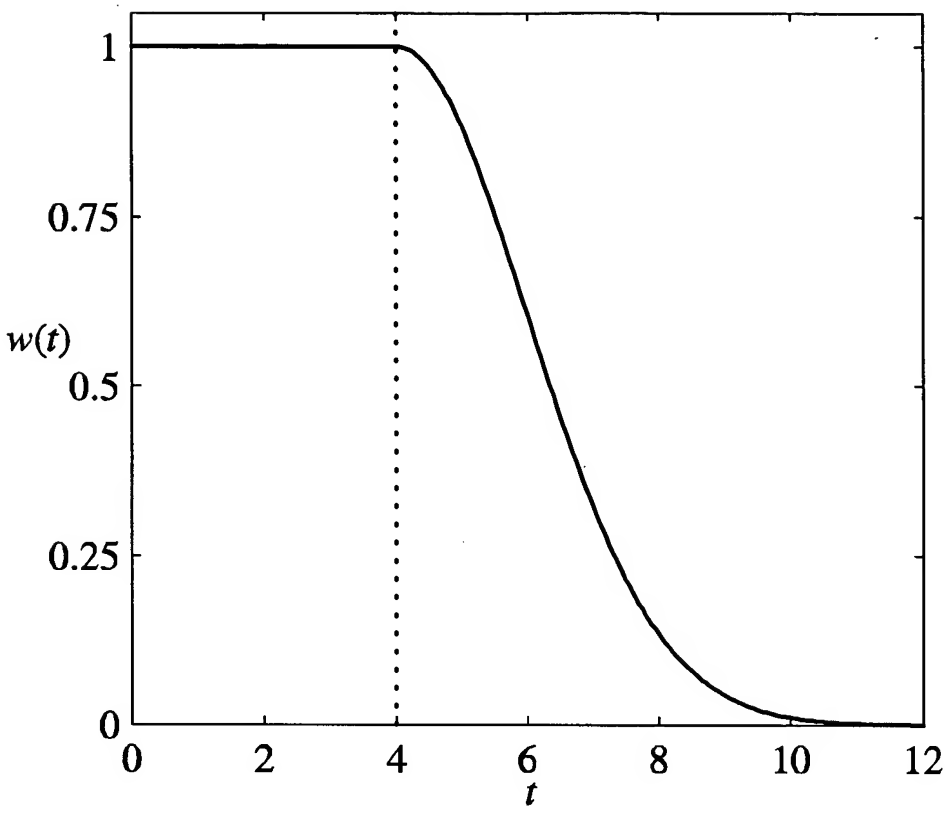


FIGURE 2

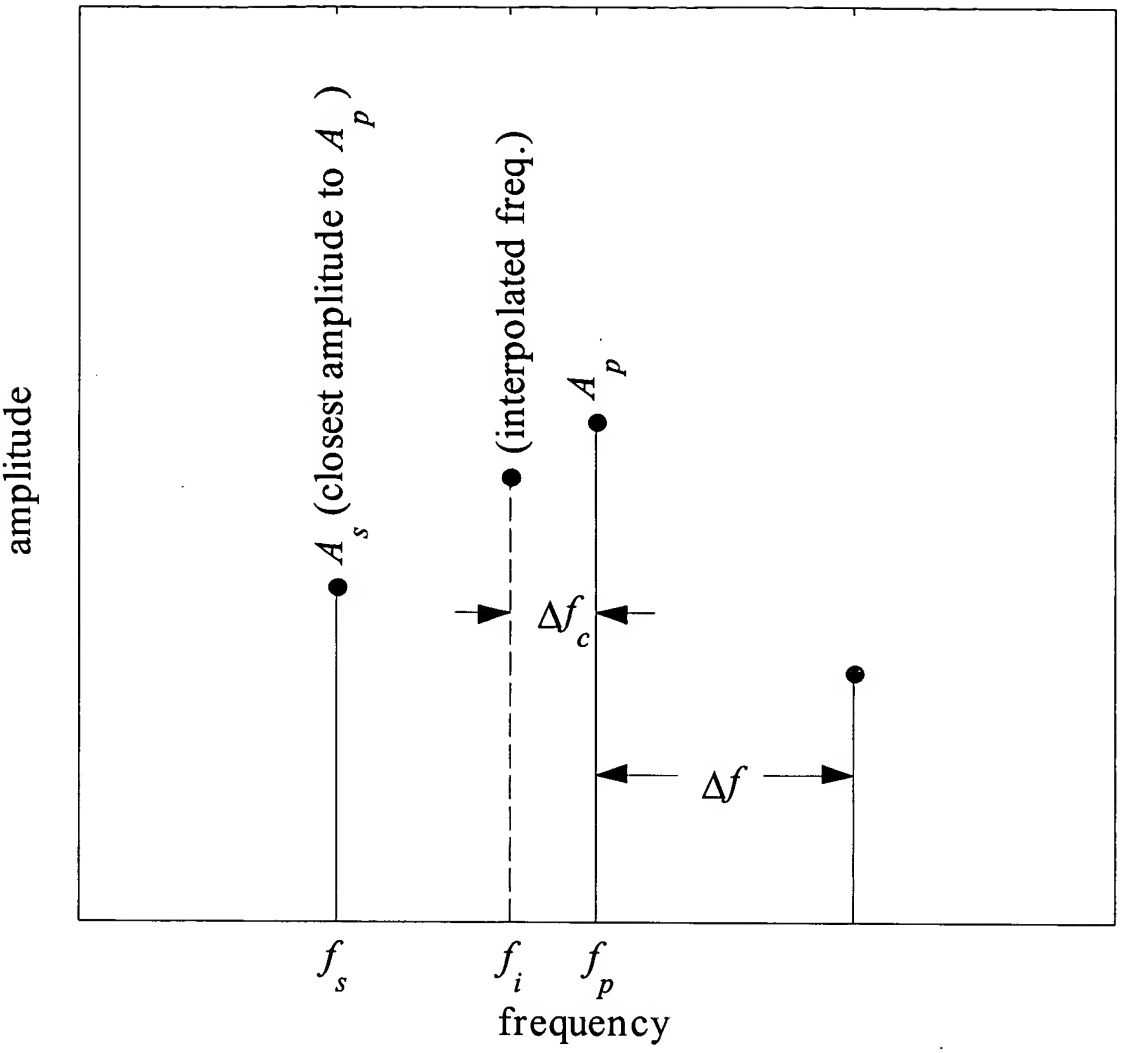

amplitude
A_s (closest amplitude to A_p)
(interpolated freq.)
A_p
Δf_c
Δf
f_s
f_i
f_p
frequency

Figure 3

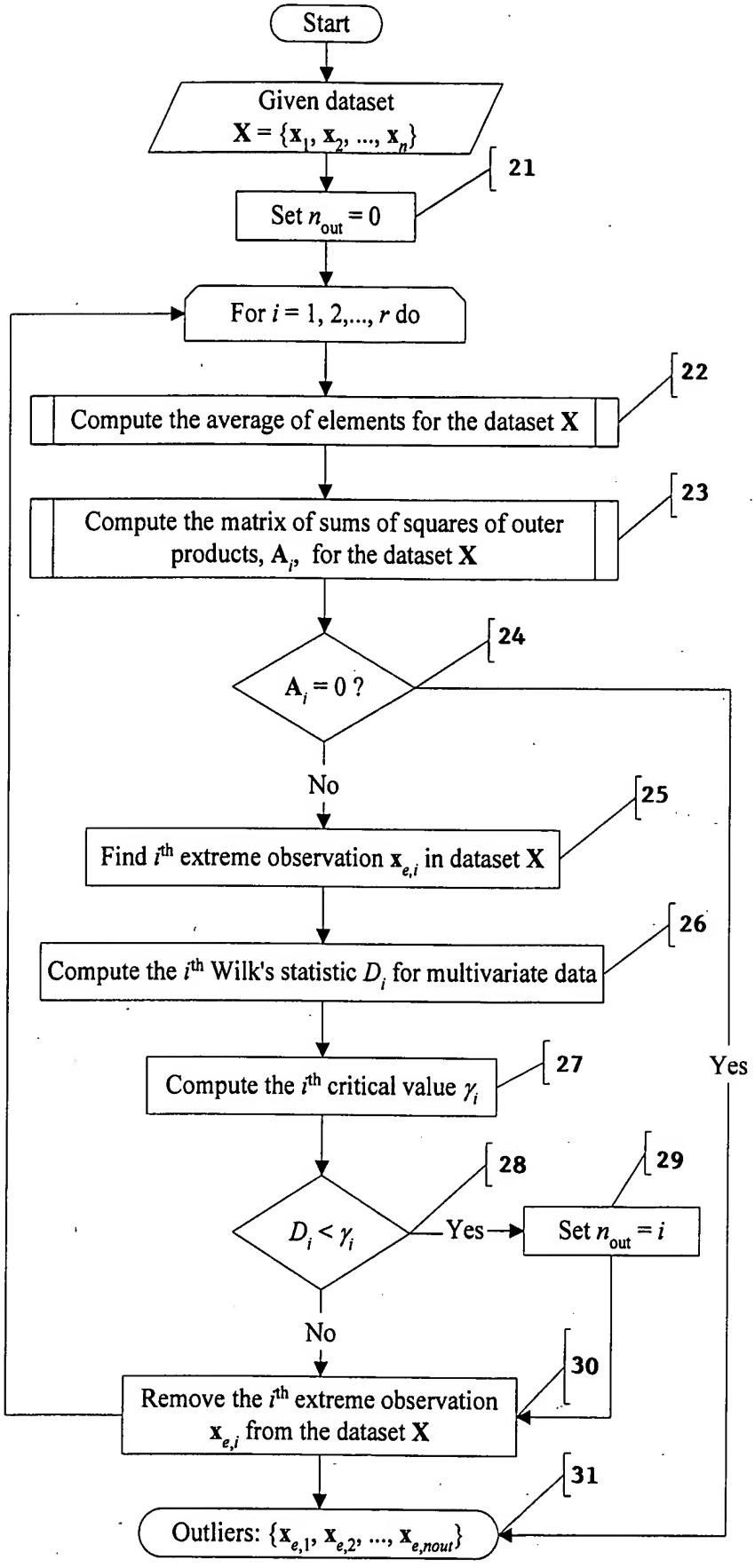

Start
Given dataset
$\mathbf{X} = \{\mathbf{x}_1, \mathbf{x}_2, ..., \mathbf{x}_n\}$
21
Set $n_{out} = 0$
For $i = 1, 2, ..., r$ do
22
Compute the average of elements for the dataset $\mathbf{X}$
23
Compute the matrix of sums of squares of outer products, $\mathbf{A}_i$, for the dataset $\mathbf{X}$
24
$\mathbf{A}_i = 0$?
No
Yes
25
Find i^{th} extreme observation $\mathbf{x}_{e,i}$ in dataset $\mathbf{X}$
26
Compute the i^{th} Wilk's statistic D_i for multivariate data
27
Compute the i^{th} critical value γ_i
28
29
$D_i < \gamma_i$
Yes
Set $n_{out} = i$
No
30
Remove the i^{th} extreme observation $\mathbf{x}_{e,i}$ from the dataset $\mathbf{X}$
31
Outliers: $\{\mathbf{x}_{e,1}, \mathbf{x}_{e,2}, ..., \mathbf{x}_{e,nout}\}$

Figure 4

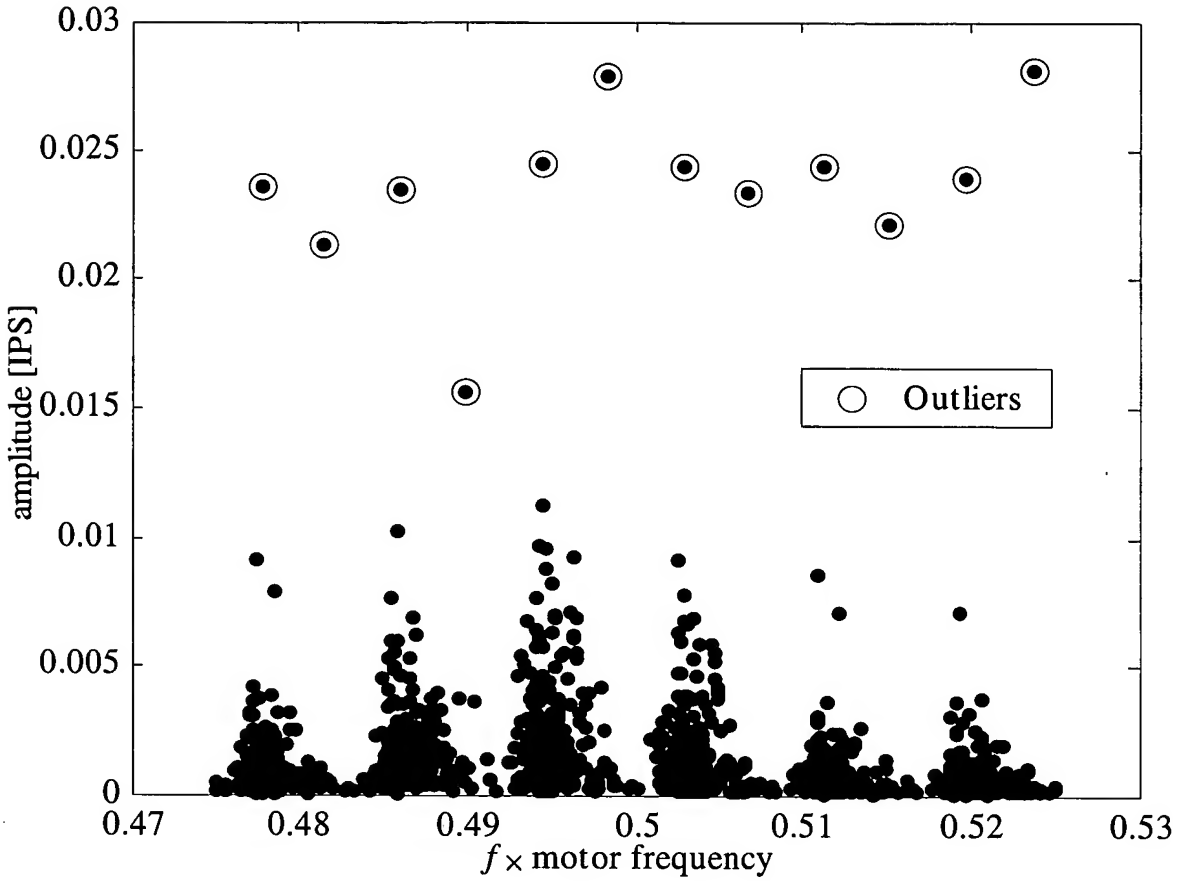
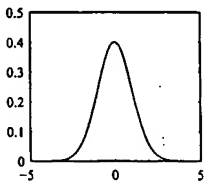
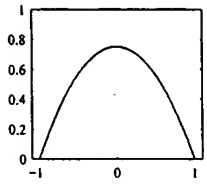
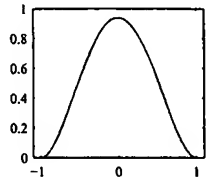
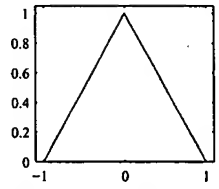

0.03
0.025
0.02
0.015
0.01
0.005
0
amplitude [IPS]
Outliers
0.47
0.48
0.49
0.5
0.51
0.52
0.53
f × motor frequency

Figure 5

	Kernel name	Definition	Plot
1.	Gaussian	$\kappa(u) = \frac{1}{\sqrt{2\pi}} e^{-u^2/2}$	
2.	Epanechnikov	$\kappa(u) = \frac{3}{4}(1-u^2)\,1_{\{\lvert u\rvert \leqslant 1\}}$	
3.	Biweight	$\kappa(u) = \frac{15}{16}(1-u^2)^2\,1_{\{\lvert u\rvert \leqslant 1\}}$	
4.	Triangle	$\kappa(u) = (1-\lvert u\rvert)\,1_{\{\lvert u\rvert \leqslant 1\}}$	

Note: $1_{\{|u|\leqslant 1\}} \triangleq \begin{cases} 1 & \text{if } |u| \leqslant 1 \\ 0 & \text{otherwise} \end{cases}$

FIGURE 6

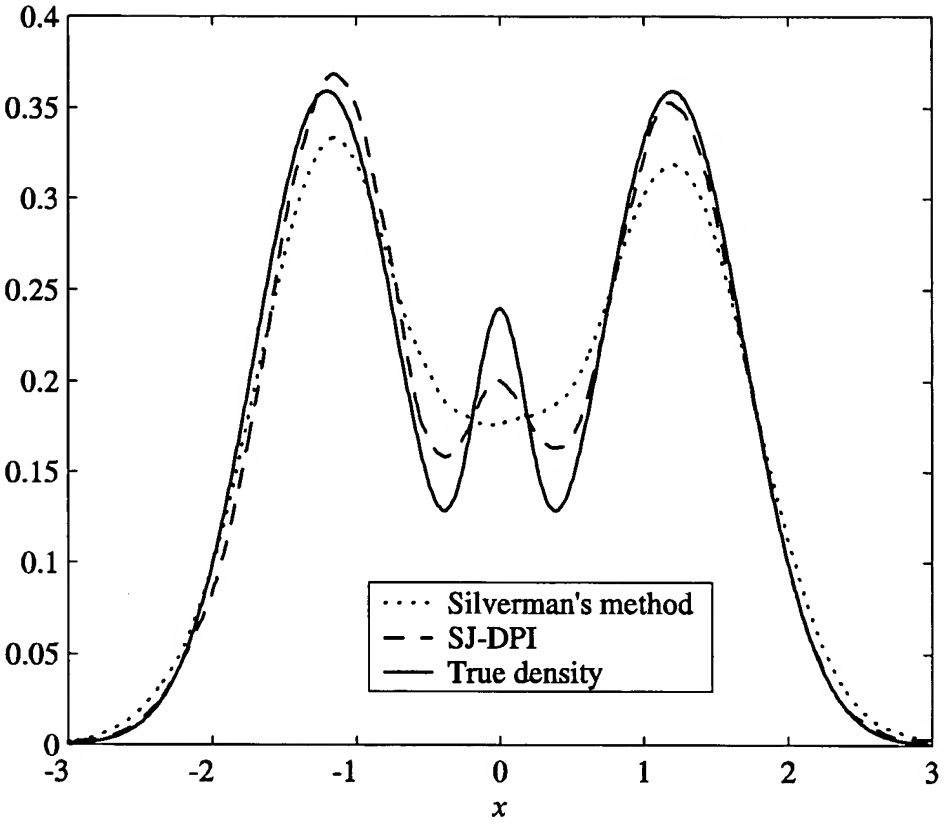

0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-3
-2
-1
0
1
2
3
x
Silverman's method
SJ-DPI
True density

FIGURE 7

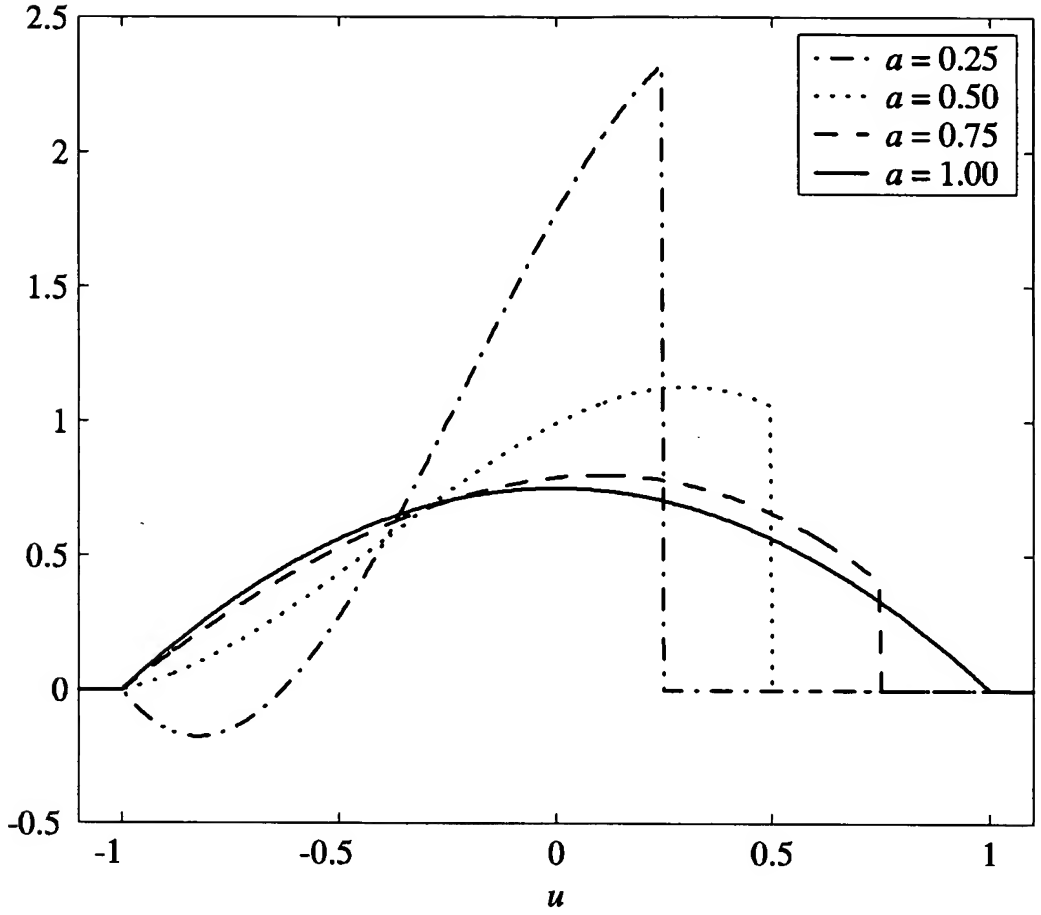


FIGURE 8

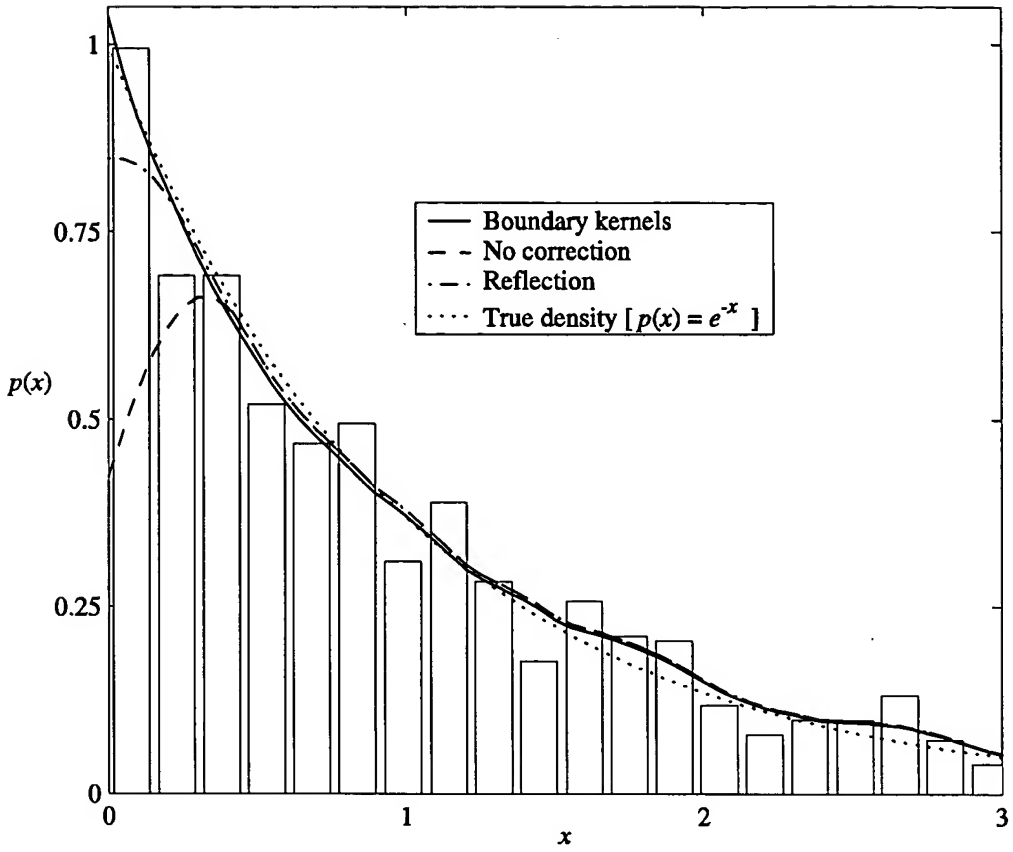

Boundary kernels
No correction
Reflection
True density [$p(x) = e^{-x}$]
$p(x)$
x
0
0.25
0.5
0.75
1
0
1
2
3

FIGURE 9

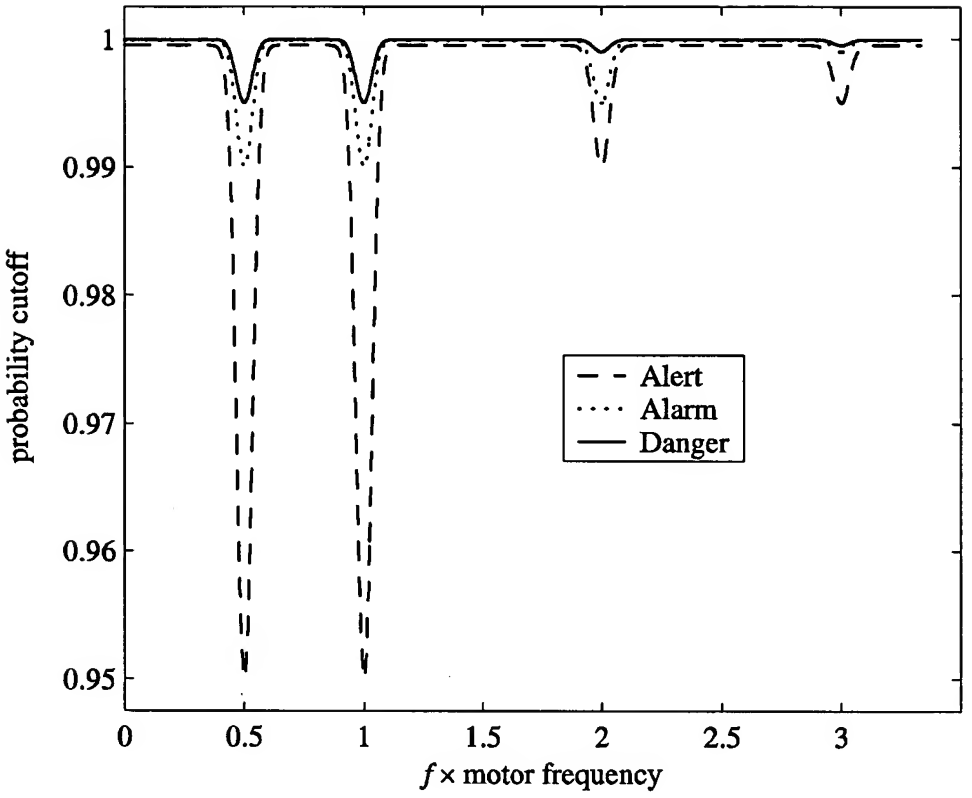

1
0.99
0.98
0.97
0.96
0.95
probability cutoff
0
0.5
1
1.5
2
2.5
3
f × motor frequency
Alert
Alarm
Danger

FIGURE 10

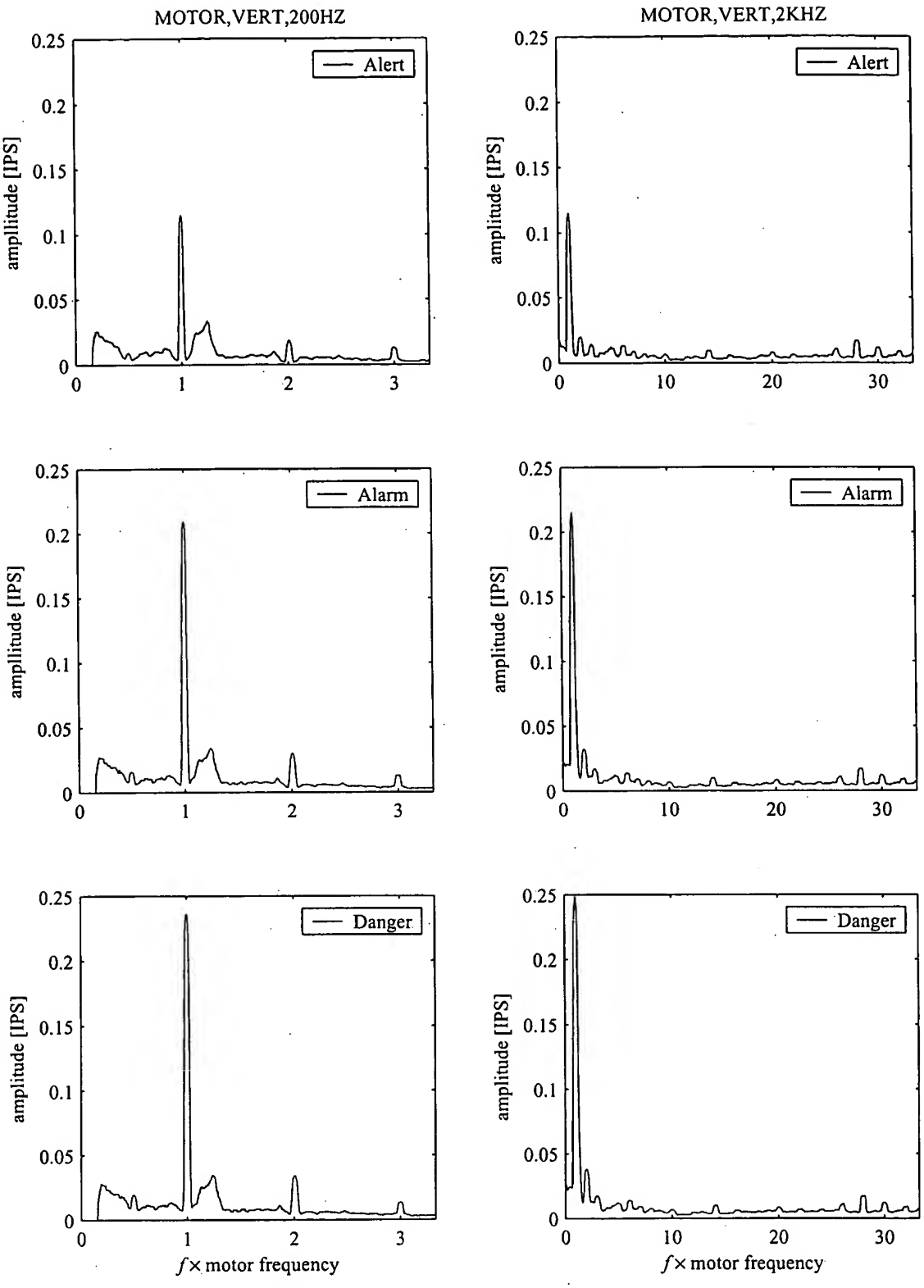

MOTOR,VERT,200HZ
MOTOR,VERT,2KHZ
Alert
Alarm
Danger
amplitude [IPS]
amplitude [IPS]
f× motor frequency
f× motor frequency

FIGURE 11

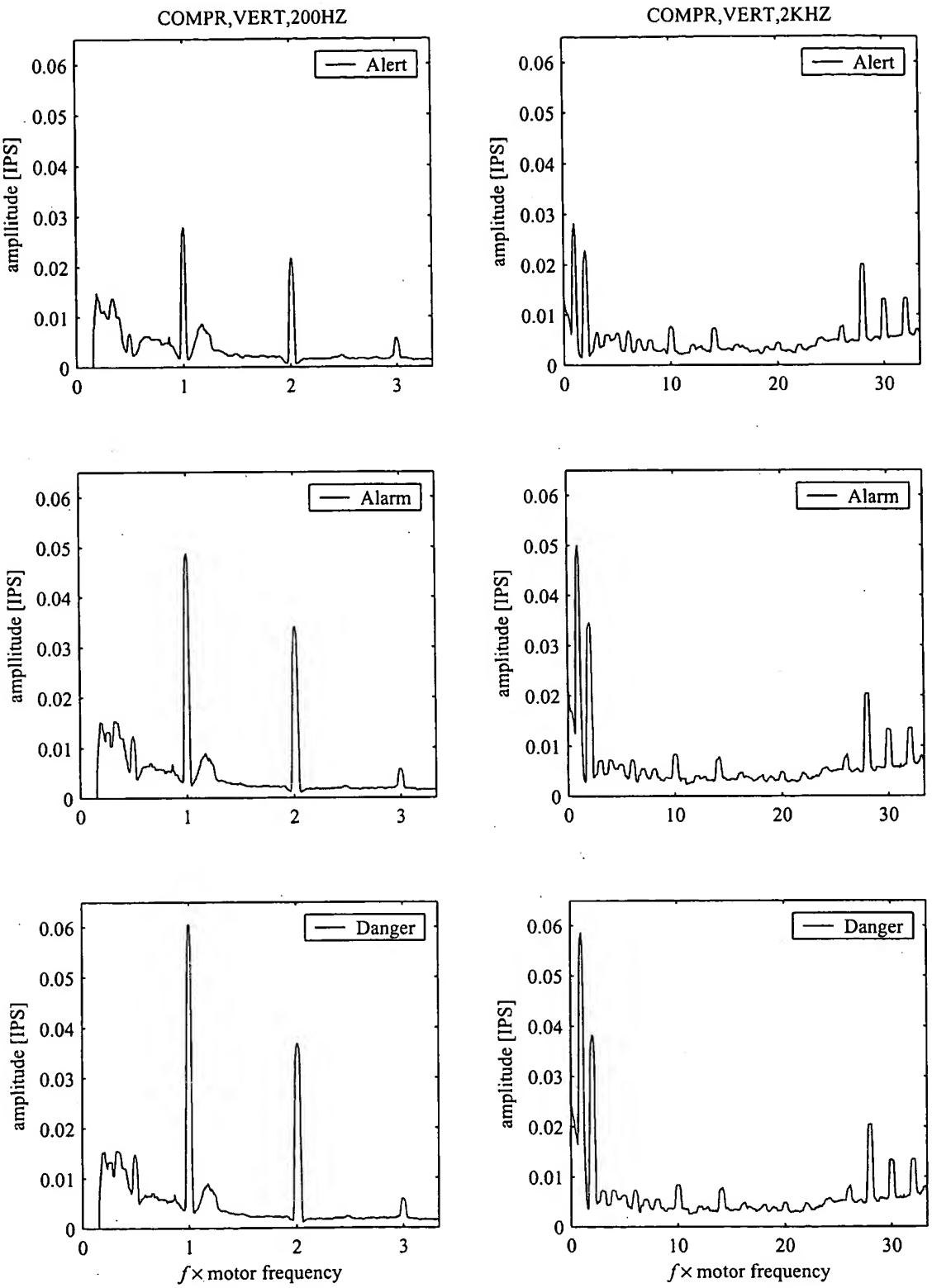

COMPR,VERT,200HZ
COMPR,VERT,2KHZ
Alert
Alarm
Danger
amplitude [IPS]
f× motor frequency

FIGURE 12